

US Frontiers of Engineering Symposia
Sponsor Award #: HR0011-12-1-0002

Final Technical Report

In 1995, the National Academy of Engineering (NAE) initiated a series of annual symposia called *Frontiers of Engineering (FOE)*. The meetings are designed to bring together a select group of the nation's emerging engineering leaders from industry, academe, and government labs to discuss pioneering technical work and leading-edge research in various engineering fields and industry sectors. The goal of the symposia is to introduce these outstanding engineers to each other, and through this interaction facilitate collaboration in engineering, the transfer of new techniques and approaches across fields, and establishment of contacts among the next generation of engineering leaders. Ultimately, this strengthens and builds US innovative capacity. At the request of overseas entities familiar with the program, FOE has expanded to include bilateral meetings with Germany, Japan, India, China, and the EU.

The US Frontiers meetings have been supported by various government agencies such as the Department of Defense and the National Science Foundation as well as corporate sponsors and a foundation. The Defense Advanced Research Projects Agency (DARPA) has been supporting the US Frontiers of Engineering meetings at the level of \$50,000/year since 1999. *This final technical report covers the most recent grant, HR0011-12-1-0002, for which the period of performance was 03/01/12 – 02/28/15.*

I. Accomplishments

During the period of performance, three US Frontiers of Engineering were organized and held:

2012 US Frontiers of Engineering

The 2012 US Frontiers of Engineering was held September 13-15 at the General Motors Technical Center in Warren, Michigan. Dr. Kristi Anseth, Distinguished Professor of Chemical and Biological Engineering and HHMI Assistant Investigator at the University of Colorado, served as chair of the symposium organizing committee. There were 102 participants with 49 from academe, 43 from industry, and 10 from government, and the topics were Climate Engineering, Vehicle Electrification, Serious Games, and Engineering Materials for the Biological Interface. In addition to the plenary sessions with 15 talks followed by discussion, on the first afternoon, there were get-acquainted sessions that provided the opportunity for all attendees to describe and answer questions about their research or technical work. On the second afternoon, GM hosted a Ride-&-Drive event where attendees could drive or ride in advanced vehicles such as the plug-in hybrid Volt and concept cars such as the two-seat EN-V that can operate autonomously. This was followed by dinner at the GM Heritage Center, which has about 200 vehicles from GM's Heritage Collection on display. The dinner speech was given by Dr. Alan I. Taub, professor of materials science and engineering at the University of Michigan,

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who spoke about the reinvention of the automobile for 21st century sustainability, describing various stages in the automotive industry from development of the internal combustion engine to the oil shock of the 1970s and the subsequent focus on fuel efficiency and safety. He concluded his talk by pointing out that if engineers are motivated to save the world, the automotive industry is a good place to do so. A book containing symposium papers was published in February 2013, and meeting video, slides, and papers were posted at the FOE website. In addition, seven of the symposium papers were published in the Winter 2012 issue of NAE's quarterly publication, *The Bridge*, which has a subscription base of over 7,000 readers.

Post-meeting feedback:

Meeting format: good or excellent – 96%

Quality of presentations: good or excellent – 97%

Opportunity to participate: good or excellent – 92%

Range of topics: about right – 100%

Gained something useful to work/research from presentations//discussion in other disciplines: 95%/97%

Identified potential collaborative opportunities//applications of interdisciplinary approaches: 90%/89%

Usefulness to professional development: useful or very useful – 97%

After the meeting, I reflected on the diverse set of topics in a wide range of engineering fields. Learning about serious games and climate engineering allowed me to consider key challenges facing the world and engineering today. Even though those topics are outside of my main area of research, they allowed me to gain perspective and presented me with ideas I can import back into my own research program. Finally, the ability to make connections and meet up-and-coming engineers was a great aspect of the Frontiers meeting.

I found it most valuable to interact with some of the brightest young engineers in the country from other disciplines. Chance of a lifetime.

This was an excellent meeting with tons of front-running ideas and discussions. It was extremely motivating and stimulated out-of-the-box thinking beyond one's single engineering discipline.

The quality of the attendees was impressive. Everyone was very professionally accomplished, and this conference was a rare opportunity to have that much "firepower" in the same place and in a format for making effective connections.

2013 US Frontiers of Engineering

The 2013 US Frontiers of Engineering was hosted by DuPont on September 19-21, and held at the Hotel du Pont in Wilmington, Delaware. Dr. Kristi Anseth, Distinguished Professor of Chemical and Biological Engineering and HHMI Assistant Investigator at the University of Colorado Boulder, served a second term as chair of the symposium organizing committee.

There were 101 participants with 50 from academe, 43 from industry, and 8 from government, and the topics were Designing and Analyzing Societal Networks, Cognitive Manufacturing, Energy: Reducing Our Dependence on Fossil Fuels, and Flexible Electronics. In addition to the plenary sessions with 15 talks followed by discussion, on the first afternoon, there were get-acquainted sessions that provided the opportunity for all attendees to describe and answer questions about their research or technical work. On the second afternoon, attendees joined one of six technical tours covering biofuels, biomaterials, solar innovations, tire testing, automotive light-weighting, and performance polymers characterization at DuPont's Experimental Station and Chestnut Run Plaza (CRP). In addition, the meeting that day was held at DuPont's CRP Building 730, which provides a highly flexible workplace, showcases many DuPont products in its building materials, and is LEED Gold certified. The dinner speech was given by Dr. Douglas Muzyka, DuPont's senior vice president and chief science technology officer. He provided an historical perspective on DuPont, a 212-year-old company that was founded as a gunpowder manufacturing company, and then moved into chemicals before assuming its current emphasis on integrated science and engineering to develop solutions to challenges in food, energy, and protection. He described the development of Bio-PDO™ and advances in cellulosic ethanol production as examples of their innovations in bio-based products, materials, and fuels. Dr. Muzyka closed by noting that the collective impact of collaboration, such as might arise from attending a meeting like Frontiers of Engineering, provides one of the best opportunities for engineering innovation. He noted that it is important to challenge boundaries, and the engineering community is in the best position to do this. A book containing symposium papers was published in February 2014, and meeting video, slides, and papers were posted at the FOE website. In addition, six of the symposium papers were published in the Winter 2013 issue of NAE's quarterly publication, *The Bridge*.

Post-meeting feedback:

Meeting format: good or excellent – 97%

Quality of presentations: good or excellent – 91%

Opportunity to participate: good or excellent – 94%

Range of topics: about right – 95%

Gained something useful to work/research from presentations//discussion in other disciplines: 91%/94%

Identified potential collaborative opportunities//applications of interdisciplinary approaches: 89%/91%

Usefulness to professional development: useful or very useful – 97%

The presentations were of high quality and accessible to non-experts. They helped to broaden my interests and become more curious about other people's disciplines. Usually when I hear talks from out of my field, it quickly goes over my head, and I zone out! It was also wonderful to meet with so many people from industry, and the lab tours were great. I've always worked in academia, and this event helped remove some of the mystery about how industry operations

I am intrigued as to why I liked so much the first session on social networks despite the lack of connection with my current work. Was it that the speakers were very engaging? Was it that the topic was of interest to me, and I didn't know? Was it that I think that this topic should be of interest to everyone? I guess what is most attractive is that we don't know how to use these data yet, and it is puzzling. I like puzzles.

There were two key aspects to the symposium for me. The first was the ability to connect with other researchers (both in academia and in industry) in my field through the breakout sessions and informal discussions. Also, the presentations on areas outside of my field were very interesting, and they allowed me to think about subjects that I would have never imaged previously.

Eureka moments sometimes come easily and others don't. I am not sure what the outcome will be, but I know that what I have learned will solidify over time and be fruitful. Overall this was a great technical growth opportunity.

I enjoyed meeting participants from different disciplines and learning a bit about the exciting things going on. I hope to discuss further with some participants to explore possibilities for collaboration.

As a result of attending this meeting I have one visit and one paper with solution format headed my way. Excellent!

2014 US Frontiers of Engineering

The 2014 US Frontiers of Engineering was held September 11-13 at the National Academies' Beckman Center in Irvine, California. Dr. Kristi Anseth, Distinguished Professor of Chemical and Biological Engineering and HHMI Assistant Investigator at the University of Colorado, served her third and final term as chair of the symposium organizing committee. There were 108 participants with 48 from academe, 48 from industry, and 12 from government, and the topics were Co-Robotics, Battery Anxiety (New Materials for Batteries), Technologies for the Heart, and Shale Gas and Oil. Following the typical US FOE format, on the first afternoon there were get-acquainted sessions that provided the opportunity for all attendees to describe and answer questions about their research or technical work. On the second afternoon, attendees met in affinity groups based on engineering discipline or interest in a particular topic such as the future of engineering education, 3D printing, or energy storage. The dinner speech, titled "What is Impact?," was given by Arunava Majumdar, Jay Precourt Professor and senior fellow, Precourt Institute for Energy and Department of Mechanical Engineering, Stanford University. He noted that despite the established ways of measuring impact in academia through papers, patents, students graduated, and awards, or in industry through building a successful company, measuring impact is an enigma. He cited the Haber-Bosch process as an example of something that may not be cited on lists of important innovations but which has had a tremendous impact on our ability to grow food and thus has had a far-reaching impact on the world's population. Dr. Majumdar challenged the attendees to discern what our Haber-Bosch-like challenge may

be, for example, providing access to electricity in developing countries or scrubbing the atmosphere of CO₂ at cost and scale. He closed by reminding attendees that we are living in a time of daunting tasks and amazing opportunities, and the value of engineering is all about people, now and in the future. A book containing symposium papers was published in February 2014, and meeting slides and papers were posted at the FOE website. In addition, eight of the symposium papers were published in the Spring 2015 issue of NAE's quarterly publication, *The Bridge*.

Post-meeting feedback:

Meeting format: good or excellent – 98%

Quality of presentations: good or excellent – 95%

Opportunity to participate: good or excellent – 98%

Range of topics: about right – 87%

Gained something useful to work/research from presentations//discussion in other disciplines: 90%/95//%

Identified potential collaborative opportunities//applications of interdisciplinary approaches: 87%/89%

Usefulness to professional development: useful or very useful – 93%

FOE was an amazing experience, and I got more out of it than I could have possibly imagined. When the conference started I wasn't sure if I would make any connections, but the connections become evident when you put the right people together. After three days I left with relationships that are leading to at least four potential research collaborations going forward, in directions I never would have expected. FOE provides a forum for interdisciplinary engineering research that is second to none. I am planning to apply for FOE grant funding in conjunction with Chris Urmson from Google (the self-driving car expert). I never would have made this connection without having the chance to collaborate via FOE.

This was probably the most useful symposium I have ever attended in my professional career. I think it has the chance to be transformative.

I know of no other meeting that brings together such a diverse group of scientists and engineers from industry, national labs, and academia. Through this experience, I forged new relationships with many people that I would have been very unlikely to meet in my normal routine of conferences and meetings. I also very much appreciated the efforts of the presenters in providing a broad context and highlighting areas of growth and challenge in each field. My appreciation for the grand challenges in the areas of energy, power, and robotics (which are not my specialty) has grown significantly.

As the above comments and feedback on the post-meeting evaluations shows, the goals and objectives of the program were achieved. Five-year surveys of FOE alumni that seek to gain a better understanding of longer-term impacts of participation in the program, also support the achievement of the program's goals: 1) Bringing together outstanding earlier career engineers

from companies, universities, and government labs to discuss technical topics, bridging traditional engineering disciplines, in order to build the nation's innovative capacity, and 2) promoting career development and creating a network of future engineering leaders to ensure the continuing vitality of the engineering profession.

II. Companion Programs and Activities that Support FOE Goals

The Grainger Foundation Frontiers of Engineering Grants. Since 2011, The Grainger Foundation Frontiers of Engineering Grants program provides funding to motivate post-symposium collaborative research and technical work among attendees of the US FOE. Two grants of \$30,000 each are given to teams of individuals who meet at the symposium and submit a proposal. The following individuals who attended the 2012, 2013, and 2014 US FOE symposia have been recipients of these grants:

2012 US FOE:

- Jordan Green (Johns Hopkins University) and Mona Jarrahi (University of Michigan for "High-performance label-free drug delivery monitoring through terahertz spectroscopy.
- Andrea Armani (University of Southern California) and Matthew Gevaert (Kiyatec Inc.) for "Real-time monitoring of cell behavior in 3D tissue scaffolds."

2013 US FOE:

- John Owens (University of California, Davis) and Tuhin Sahai (United Technologies Research Center) for "Parallel matrix factorization: Towards GPUs in the data center."
- Philip Feng (Case Western Reserve University) and Tse Nga (Tina) Ng (Palo Alto Research Center) for "Integrating atomically thin semiconducting crystals with flexible electronics."

2014 US FOE:

- Danielle Tullman Ercek (University of California Berkeley) and David Mascarenas (Los Alamos National Laboratory) for "Structural materials capable of precisely timed, self-degradation: A synthetic/chemical biology approach."
- Andrea Alu (University of Texas at Austin) and Luke Sweatlock (Northrop Grumman Aerospace Systems) for "Pushing the limits of thermal management and radio communications using time-modulated metasurfaces."

Armstrong Endowment for Young Engineers—Gilbreth Lectures. The Gilbreth Lectures were established in 2001 by the Council of the National Academy of Engineering as a means of recognizing outstanding young American engineers and making them more visible to the NAE membership. Recipients of the lectureships are outstanding speakers at FOE meetings who are invited to give their presentations at NAE's Annual Meetings in October and National Meetings in February. It is important to note that at the NAE National Meeting, students from high schools that serve underrepresented communities are invited to the meeting and thereby are exposed to dynamic FOE speakers, engineering topics, and the importance of engineering to our nation's endeavors. So far 60 FOE speakers have been honored with the Gilbreth Lectureship.

Community-Building Activities

In addition, there are a number of mechanisms to build upon the relationships developed at the symposia. Each attendee is given access, via the website, to a “Staying in Touch” document that describes the networking support that is available. This ranges from an FOE community on LinkedIn to grants for post-meeting collaborative work. The Frontiers of Engineering website includes an FOE Community feature where alumni can update their profiles, access full directory information, and post news items. There is also an FOE Alumni Spotlight, which highlights the research of FOE alumni, and easy navigation to presentation papers, presentation slides, and video. The FOE Alumni Newsletter—a mechanism for FOE alumni to share information about their research, technical work, and other professional activities—is published twice a year. Frontiers alumni remain involved with the program and secure new contacts by serving on organizing committees, becoming speakers at the meetings, and attending the bilateral Frontiers symposia.

Increasing the Visibility of Engineers and the Role of Engineering in Society

An important outcome of the program is making sure these outstanding younger engineers—and their talents—become more visible to a larger community, whether it is Academy programs or advisory groups that require the expertise of engineers. The Frontiers searchable database has proven useful for Academy staff seeking individuals to participate in activities such as the Keck Futures Initiative and for service on National Research Council committees and panels; media contacts seeking engineers for articles or other outreach activities; and government agency sponsors looking for engineers for their boards and panels. In the past year, FOE alumni names have been forwarded for service as experts on engineering career paths in the aerospace industry and on big data, judges for NAE’s Engineering for You video contest, and attendees of Japan’s Science and Technology in Society Forum, among others.

In addition to opening service opportunities for the nation’s outstanding young engineers, another outcome of this symposium series is that a wider audience is made familiar with the topics presented at the meeting. The FOE website (www.naefrontiers.org) makes symposium content—including symposium papers and abstracts, profiles of attendees, and video of presentations—available to the broader public. Publications such as the US FOE symposium volume and US FOE papers published in a special issue of NAE’s quarterly journal, *The Bridge*, also bring the content of the symposia to a broader audience. Through digital and print media as well as other outreach efforts, the Frontiers of Engineering symposia serve an important role in informing a broader community about the state of engineering research and technical work today.

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